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ON THE POSSIBLE POLARIZATION OF SOLAR FLARES' X-RAY BREMMSTRAHLUNG

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SUMMARY

The polarization of X-ray bremmstrahlung of solar flares is assumed on the basis of this possibility for cosmic X-ray radiation and also because in the course of solar flares the emergence of sharply anisotropic beams of accelerated electrons can be expected. Conclusion is also derived that when it is attempted to determine the emission mechanisms in the course of polarization observations, these should be conducted in at least two energy regions of photons, sufficiently apart from one another.

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The hard X-ray emission of solar flares in the region $\lambda \lesssim 8$ A may occur, in principle, as a result of three emission mechanisms: bremmstrahlung, synchrotron and Compton. Disposing only of experimental data on the spectral flux, it is difficult to point to the prevailing emission mechanism for concrete flares, as the information on the energy spectrum of accelerated electrons and on physical conditions in the radiation region are so far unreliable. This is why it would be important to attempt to detect the polarization of solar flares' hard radiation.

A possible polarization of cosmic X-ray emission is considered in ref.[1] for the above three emission mechanisms. Conclusion is derived at the same time that the detection of noticeable linear polarization will imply that the X-ray radiation is either synchrotron, or it has a bremmstrahlung nature, provided the angular distribution of emitting electrons is anisotropic. Considered below is the second possibility, for at solar flares one may naturally expect the emergence of sharply anisotropic beams of accelerated electrons.

(*) O VOZMOZHNOY POLYARIZATSII TORMOZNOGO RENGGENOVSKOGO IZLUCHENIYA SOLNECHNYKH VSPYSHEK.

It is not difficult to show that for a parallel monoenergetic beam of electrons of low energy ($E_к \ll mc^2$) moving at an angle θ to the visual ray $\vec{k}$, the degree of linear polarization is determined by the expressions (see, for example, [2]) :

$$\Pi = (\sigma_\perp - \sigma_\parallel)/(\sigma_\perp + \sigma_\parallel) = -B\sin^2\theta/(B\sin^2\theta + C), \tag{1}$$

where $\sigma_\perp$ is the bremmstrahlung cross-section related to photons, polarized perpendicularly to the emission plane [plane $(\vec{p}\vec{k})$], θ is the angle between $\vec{p}$ and $\vec{k}$, and the quantities B and C are respectively

$$\begin{aligned} B &= (3x-2)\ln(1+\sqrt{1-x})/(1-\sqrt{1-x}) + 6\sqrt{1-x}, \\ C &= 2(2-x)\ln(1+\sqrt{1-x})/(1-\sqrt{1-x}) - 4\sqrt{1-x}, \end{aligned} \tag{2}$$

where $x = E_\gamma/E_к$, E_γ is the energy of the photon, and E_k is the kinetic energy of the electron. Formulas (1) - (2) were obtained in the Borne approximation, the shielding being neglected.

The dependence of the degree of linear polarization Π and of the total emission power P_γ on the energy of photons for various angles θ is plotted in Fig.1. It may be seen from the diagram that in the region of soft photons ($x \ll 1$) the polarization is positive, that is, photons are polarized mainly perpendicularly to the emission plane, while the hard photons ($x \lesssim 1$) are polarized in that plane. The degree of polarization reaches 100% in the indicated two limiting cases and passes through zero independently of the angle θ for $x = E_\gamma/E_к \approx 0{,}12$. This singularity of bremmstrahlung polarization allows us to distinguish it from the synchrotron radiation. For synchrotron radiation of the monoenergetic beam of relativistic electrons the degree of polarzation is significantly less dependent on the frequency and is comprised within the limits 50 — 100%, while the direction of the prevailing polarization is determined by the projection of the magnetic field on the pictorial plane (see, for example, [3]).

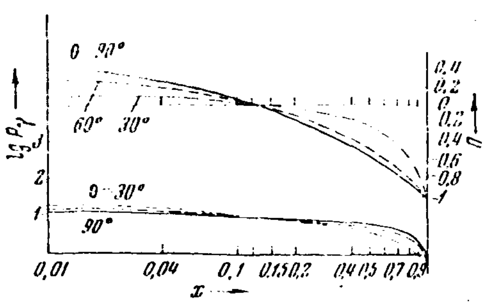

Fig.1

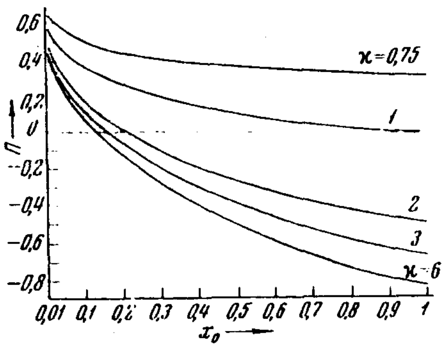

Fig.2

It is natural to expect that the electrons, accelerated during flares, have a certain energy distribution. The polarization properties of the radiation will then also depend upon the properties of the energy spectrum.

The dependence of the degree of polarization Π on $x_0 = E_\gamma / E_{\kappa 0}$ ($E_{\kappa 0}$ is the boundary of the energy spectrum of electrons from the side of low energies) at $\theta_0 = \pi/2$ for the exponential spectrum of electrons $E_k^{-\kappa}$ at different values of κ is plotted in Fig.2. It may be seen from that figure that for a steep energy spectrum ($\varkappa \gg 1$) the degree of polarization varies as previously from $+1$ to -1, passing through zero near $E_\gamma \approx 0{,}12 E_{\kappa 0}$. As $\varkappa$ decreases, the zero point shifts toward the region of greater values and vanishes for $\varkappa \leqslant 1$. If the energy spectrum of electrons has a steep drop or is discontinued in the relativistic region $E_\kappa \gg mc^2$, it is easy to show that the zero point is also absent and all photons are polarized perpendicularly to the emission plane.

The indicated properties of bremmstrahlung polarization are valid only for a parallel beam of electrons. Either limiting case may be materialized during flares, when the electrons are trapped by the regular magnetic field, and a certain angular distribution of velocities is settled in the trap. The degree of polarization is then naturally decreased. Let us consider this important case on the example of sinusoidal angular distribution of the form $\sin^n\alpha$, where α is the angle between the velocity and the magnetic field (or any other chosen direction). Such a distribution, or a distribution close to it, is established, for example, in the radiation belt of the Earth or of Jupiter [4, 5]. Averaging by the angular distribution, we shall obtain for the degree of polarization Π the expressions

$$\Pi_{n=2} = B\sin^2\theta_0/(4B + 5C - B\sin^2\theta_0),$$
$$\Pi_{n=4} = B\sin^2\theta_0/(3B + 3{,}5C - B\sin^2\theta_0), \qquad (3)$$

where θ_0 is the angle between the distributions symmetry axis (direction of the magnetic field) and the visual ray, while the coefficients B and C are as previously determined by (2). It follows from (3) that in the presence of angular distribution the degree of polarization is smaller than for the parallel beam of electrons (see (1)). At the same time, Π is zero if the axis of symmetry of the angular distribution coincides with the visual ray ($\theta_0 = 0$), and maximum at $\theta_0 = \pi/2$.

The frequency dependence of the degree of polarization is plotted in Fig.3 for the indicated particular case and for various values of the angle θ_0 and also for the values n = 2 and n = 4.

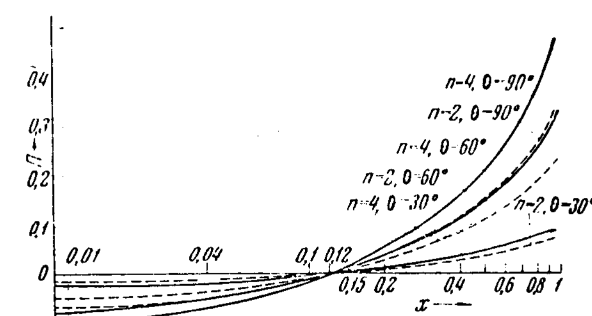

Fig.3

It may be seen from this figure that the averaging by the sinusoidal distribution does not affect the characteristic property of bremmstrahlung polarization. The degree of polarization passes as previously through zero near $E_\gamma \approx 0{,}12 E_\kappa$ independently of the angle θ_0, whereupon soft photons are polarized mostly in the plane passing through the axis of symmetry of the angular distribution and the visual ray. However, the value of the polarization maximum is substantially less than for a parallel beam of electrons, and rises as the degree n of anisotropy increases. For example, at n = 4 the polarization maximum is reached in the region of hard photons for $\theta_0 = \pi/2$, and is equal to 50%.

If the angular and energetic distributions of electrons are independent, it is not difficult to conduct the averaging by both these distributions. At the same time, for the cases considered above of exponential energy spectrum and of sinusoidal angular distribution we shall obtain the same expressions (3) in which B and C should be substituted by b and c, whereupon

$$b = \left(\frac{3}{2}\frac{2\varkappa-1}{2\varkappa+1}x_0 - 1\right)l_0 + F_1\left(3 - \frac{2}{2\varkappa-1}\frac{F_2}{F_1} + \frac{3(2\varkappa-1)}{(2\varkappa+1)^2}x_0\frac{F_3}{F_1}\right), \tag{4}$$

$$c = \left(2 - \frac{2\varkappa-1}{2\varkappa+1}x_0\right)l_0 - 2F_1\left(1 - \frac{2}{2\varkappa-1}\frac{F_2}{F_1} + \frac{2\varkappa-1}{(2\varkappa+1)^2}x_0\frac{F_3}{F_1}\right). \tag{5}$$

The following denotations were utilized in (5):

$$\begin{gathered} x_0 = E_\gamma/E_{\kappa_0}, \quad l_0 = \ln\left(1+\sqrt{1-x_0}\right)/\left(1-\sqrt{1-x_0}\right), \\ F_1 = F(-{}^1/_2, \varkappa - {}^1/_2, \varkappa + {}^1/_2, x_0), \\ F_2 = F({}^1/_2, \varkappa - {}^1/_2, \varkappa + {}^1/_2, x_0), \quad F_3 = F({}^1/_2, \varkappa + {}^1/_2, \varkappa + {}^3/_2, x_0) \end{gathered} \tag{6}$$

are hypergeometrical functions.

In the limit case of small values $x_0 \lesssim 0{,}2$ $F_1 \approx F_2 \approx F_3 \approx 1$, $l_0 \approx \ln(4/x_0)$, and this is why

$$\begin{gathered} b \approx \left(\frac{3}{2}\frac{2\varkappa-1}{2\varkappa+1}x_0 - 1\right)\ln\frac{4}{x_0}\frac{6\varkappa-5}{2\varkappa-1}, \\ c \approx 2\left(\ln\frac{4}{x_0} - \frac{2\varkappa-3}{2\varkappa-1}\right). \end{gathered} \tag{7}$$

In the opposite limit case $E_\gamma \geqslant E_{\kappa_0}$ we should postulate $x_0 = 1$ and $l_0 = 0$, then

$$b \approx \frac{4\sqrt{\pi}(\varkappa-1)}{2\varkappa+1}\frac{\Gamma(\varkappa-{}^1/_2)}{\Gamma(\varkappa)} = (\varkappa-1)\,c \tag{8}$$

(Γ is the Euler gamma-function).

As should have been anticipated, at averaging by the angular and energetic distribution, the maximum degree of polarization is still less, and reaches relatively great values only at $\theta_0 = \pi/2$ and high values of κ. For example, it follows from (3), (5) - (9) that at $\theta_0 = \pi/2$ the degree of polarization reaches 37% at $\kappa = 6$ only in the region of hard photons, while in that of soft photons it is significantly lower. However, one may hope, even for this case, that in real conditions the degree of polarization of bremmstrahlung will be of the order of 10 to 20%, and one may hope to be able to detect it.

If the energy spectrum of electrons accelerated during the flare continues into the nonrelativistic region, the bremmstrahlung will considerably exceed the two other forms of emission: the Compton and synchrotron emissions [6].

At the same time, the X-ray radiation may be linearly polarized, as was shown above, and the degree of polarization may in certain cases attain 100 percent. The polarization of this radiation depends on the frequency (for the synchrotron radiation the polarization in a wide frequency range does not depend on frequency when the distribution E_{k0} is exponential, and is equal to $(\kappa + 1)/(\kappa + 7/3)$ (see, for example, [3])) and when the energy spectrum is discontinued at a certain frequency E_{k0} , it has a very characteristic singularity in the region where $E_\gamma < E_{\kappa 0}$ (the sign being different for soft and hard photons), which provides us with the possibility of distinguishing bremmstrahlung from synchrotron radiation.

This is why, when in the course of polarization observations setup one is attempting to determine the emission mechanism, it is desirable to conduct the observations at least in two energy regions of photons, sufficiently remote from one another.

**** THE END ****

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